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ABSTRACT

Industry seismic reflection profiles shot in the 60's and early 70's in the central Persian (Arabian) Gulf are used to map two late Tertiary unconformities, and velocity data from a centrally located well is used to convert travel time to depth to the unconformities. The deeper horizon correlates with a regional unconformity at the end of the Eocene in most wells and dips monotonically to the northeast, whereas the shallower horizon is flatter and correlates with the mid-upper Miocene section in one well. Isopach maps based on wells indicate that sedimentation was relatively uniform across the region until the middle to late Miocene. Sediments deposited since the late Miocene thicken from 100-200 m on the Arabian side of the Gulf to >1000 m near Iran reflecting deposition of sediments eroded from the rapidly uplifting Zagros fold-belt. As a result of the rapid deposition, the velocity gradient in the upper 1 km decreases from ~4 km/sec per km near Arabia to about 2 km/sec per km on the Iranian side of the Gulf.

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Final Report to ONR
Stratigraphic development of the central Persian Gulf during the Neogene

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LONG TERM GOALS

The Persian (Arabian) Gulf is a shallow (<110 m), epicontinental basin formed on the Arabian plate in mid-late Miocene. There is little publicly available information on the Neogene sediments most of which were shed from the Zagros uplift in Iran. Our long-term goal is to understand how variations in source, tectonic subsidence, climate, and sea level affected sedimentary processes and stratigraphic development of an arid, shallow-marine environment.

BACKGROUND

Continental collision along the Zagros suture raised a mountain belt in central Iran in the late Miocene. This uplift shed great quantities of sediment towards the southwest reaching the present Gulf basin but not Saudi Arabia and, later, initiated southwestward sliding of the Zagros fold and thrust sheet. The shallow stratigraphy of the Gulf is comprised of a 0.2-2 km wedge of fine-grained orogenic clastics thickening to the northeast. Published industry studies have largely ignored the stratigraphic development of the wedge in response to uplift of the Zagros and the effects of the propagating deformation front on the wedge.

OBJECTIVES

The objective of this project was to define the broad-scale lateral and temporal patterns in late Cenozoic stratigraphy in the central portion of the basin. I hoped to use newly available industry data to better constrain the ages of Neogene seismic units in the Gulf and to map their shape, thickness, and development with time. A secondary objective was to compile industry seismic profiles and velocity data from wells into a form that could be used to predict vertical and lateral velocity variation in the 0.5-1 km interval below the seafloor.

APPROACH

Richard Simmons at Navoceano (N5) provided funds (as an expansion to this grant) for the purchase from Masera Corporation of logs from 26 Iranian wells in the Gulf and paper copies of ~5,000 km of multi-fold industry seismic profiles. Based on area covered, 50-60% of the seismic profiles are of such low quality in the Cenozoic section (upper 0.5-0.9 sec) that it is difficult to recognize reflectors much less unconformities. In addition to the Masera data, we interpreted seismic profiles from an *Atlantis II* cruise in 1977 and used published formation tops for 17 additional wells in the Gulf and Iran and 12 wells in Iraq.

ACCOMPLISHMENTS AND RESULTS

CDP points for the industry profiles were digitized and plotted. Tables of sonic log velocity, calibrated with check-shot profiles, were typed into computer files and plotted. Both interval and "average" velocities are available. The well reports contain formation tops for only two wells. Time datums were picked from logs in at least parts of 10 other wells. Interval velocities and well geology were correlated to seismic profiles crossing near each well. We identified several Neogene seismic events, but the only feature that can be traced across the central basin is the unconformity at the Eocene-Oligocene boundary. We traced a shallower horizon in many profiles. However, we obtained a range of well ages within the Miocene for the horizon, so we have little confidence in the details of our maps of this feature. Unit thickness was computed using a sonic log velocity profile calibrated with check-shot travel times. Poor quality data in the upper 0.5 sec prevents confident mapping of any horizons younger than Miocene in age.

The primary feature of the Eocene-Oligocene surface is a deepening from ~0.2 near Arabia to ~1.6 km near Iran. Secondary features include uplift due to arches in the Paleozoic basement, Quaternary folding near the Iranian coast, and salt movement. The Miocene (?) datum is flatter and shows more variability due to local salt movements and crustal tectonics.

The well geology indicates a major change in sedimentation during the Miocene. In the Paleocene-Eocene, shallow marine carbonates and anhydrite were deposited relatively uniformly (300-800 m thickness). The thickness of the overlying lower-middle Miocene unit (Asmari-Ghar) also appears relatively uniform, being somewhat greater in Kuwait where a southwest source fed the Ghar-Ahwaz delta. In contrast to the older formations with their uniform thickness, the post-middle Miocene unit clearly thickens from southwest to northeast. The high thickness variability displayed by this unit along the coast of Iran (3492 vs. 215 m) reflects sedimentation controlled by tectonics in the Zagros fold belt. The thick emplacement of the Neogene sediments to the northeast depressed the earlier formations causing all structure maps of the pre-late Miocene units to dip towards Iran. In the north end of the Gulf Miocene datums in wells shallow from ~1.8 km near Karg Island to <0.5 km in southeast Iraq.

The compressional velocity structure of the sedimentary section in the central Gulf is primarily controlled by lithology and age. The positive velocity gradient in the upper 1-1.5 km is ubiquitous and is likely due to dewatering, compaction, and carbonate alteration processes affecting all sediment types across the Gulf. Velocity increases from 1600-1900 m/sec at the seafloor to a peak in the Paleocene below which velocity decreases with depth in the Upper and middle Cretaceous. Velocity increases with depth again from an unconformity at the base of middle Cretaceous through the Lower Cretaceous and Jurassic with local minimums in the middle of the Upper and Lower Jurassic. Velocities and velocity gradients in the Mesozoic section are very similar from region to region reflecting uniform sedimentation of predominantly shallow water platform carbonates with vertically varying proportions of evaporite and continental clastic facies.

Although the overall velocity structure is consistent across the Gulf, details of the shallow velocity structure reveal distinct regional differences controlled by the northeastward thickening of the post-middle Miocene sediment wedge. We computed average interval velocity profiles for three regions extending from Arabia northeastward to Iran. On average, the velocity peak that correlates with the Paleocene interval decreases in velocity from 5200 m/sec in the southwest to only 4400 m/sec in the northeast while the depth of the peak increases from 900 m to 1300 m. This velocity decrease is probably the result of the northeastward increase in the marl content of Paleocene/early Eocene carbonate and evaporite strata. The Paleocene peak is missing in wells above a prominent salt dome. In the northeast and central portions of the Gulf, a velocity peak above the regional gradient occurs in a 200-300 m thick layer that appears to correlate with the Asmari Limestone. The interval thins towards the southwest and disappears on the Arabian side of the Gulf. In the central region, velocity values cluster near 1900-2000 m/sec from the seafloor to ~350 m and near 2700 m/sec at 350-450 m depth, but these layers do not appear to the northeast and are less apparent in profiles to the southwest. The vertical uniformity of velocity in these units is likely due to rapid deposition of sediment of similar composition and grain size. The velocity gradient from the seafloor down to the Paleocene high increases from only 2.0 km/sec per km near Iran to 3.0 km/sec per km in the central Gulf and to 3.9 km/sec per km off Arabia. The average seismic velocity at 1 km depth decreases from near 5 km/sec near Arabia to 3.5 km/sec closer to Iran. The gradient change is due primarily to greater thicknesses of fine-grained clastics deposited proximal to the Zagros uplift in the Miocene-Pliocene and secondarily to lateral facies change in the early Tertiary.

Well and seismic data indicate that the effects of the Zagros Mountain uplift reached the Gulf region at the end of the Miocene. At well D-1 near Iran in the northern end of the study area, the sediments forming the thickest portion (100-590 mbsl) of the Neogene section are silty and sandy marls with sandstone interbeds that are late Miocene-Pliocene in age (Mishan-Agha Jari). These sediments were deposited at ~52 m/Ma in a shallow marine to lagoonal environment with thin evaporite layers indicating restricted circulation. Overlying this unit are ~80 m of Quaternary fine-grained clastics with well-preserved marine microfossils

deposited at 43 m/Ma in a shallow, open-marine environment. This unit correlates with the Bakhtyari Formation in Iran where it is comprised mostly of conglomerates and other subaerially deposited coarse-grained clastics. Although the paleoenvironment became more open marine at the end of the Agha Jari (end of the Pliocene), the gross accumulation rates remained about the same indicating that overall sediment supply rate did not change significantly as the Zagros deformation approached the present Gulf.

The geologic section at the D-1 well indicates that the present Gulf was a shallow restricted marine shelf during the early Neogene and received distal clastic sediments from the suture zone and region tectonic uplift in Iran during the latest Miocene. Most of the Neogene wedge of sediments defined by our seismic structure maps and well data were deposited during the early stages of uplift when rivers could transport sediment without restriction to the southwest. The relatively uniform velocity layers observed in some central Gulf wells indicate that emplacement was episodic. These events could be associated with sudden tectonic changes in the uplift region or to changes in climate or eustatic sealevel, however our well stratigraphy is not defined well-enough to confidently correlate these events to changes elsewhere. Subsequent deformation in the Zagros fold belt did not reduce the rate of sediment supply to the Gulf region. Southwestward propagation of the deformation front substantially thickened the Phanerozoic sediment section on the plate causing subsidence in the present Gulf leading to more open marine conditions during the Quaternary. The present Gulf environment is not characteristic of sedimentation conditions during the deposition of the thickened Neogene sequence, although fine-grained clastics are the most common facies since the middle Miocene.

IMPACT/APPLICATIONS

The deepening of the Miocene and Eocene/Oligocene horizons towards the northeast reflects tectonic subsidence driven by a shifting sedimentary load on the plate due to the southwestward sliding of the Zargos fold belt along a deep salt layer. The northwestward shallowing of Cenozoic datums across the northern end of the Persian Gulf indicates that tectonic subsidence in the Mesopotamian valley of Iraq is slower than subsidence in the Persian Gulf. We infer that the present partition of the depression into water and land areas is due to differences in subsidence rate and not to higher supply rates of sediment in Iraq.

The quality of the well velocity data is much better than other velocity data that are publicly available. The well data clearly demonstrate that the vertical changes are controlled by lithology, compaction, and alteration and that the broad-scale horizontal changes are controlled by the northeastward thickening of the Zagros wedge. Superimposed on these regional large-scale patterns are local deviations of 10-30% which we attribute to geological processes that formed the wedge. The data are insufficient to map these deviations.

TRANSITIONS

The Geospatial Data Base group at Navoceano will use the Masera well velocities in future revisions to their Persian Gulf layered velocity model data base. One of the primary objectives of our 1998 cruise will be to obtain interval velocities from multi-channel semblance data and refraction velocities from the sonobuoys. These data will provide direct, systematic measurements of seafloor velocity data base for Navy operations in the Persian Gulf. The well data obtained in the present study will provide essential *in-situ* velocity data to check the resolution and accuracy of the underway geophysical data.

PUBLICATIONS

The data and interpretations of this study are presented in

Late Cenozoic geology of the central Persian (Arabian) Gulf from industry well data and seismic profiles, S.A. Swift, E. Uchupi, and D.A. Ross, WHOI Technical Memorandum 01-98, April, 1998.

We used the Masera well data in the following report in preparation:

Uchupi, E., S.A. Swift, D.A. Ross, Late Quaternary stratigraphy, paleoclimatology, and neotectonism of the Persian (Arabian) Gulf region.